3rd Aeroelastic Prediction Workshop (AePW-3) Flight Test Working Group

Jeffrey Ouellette

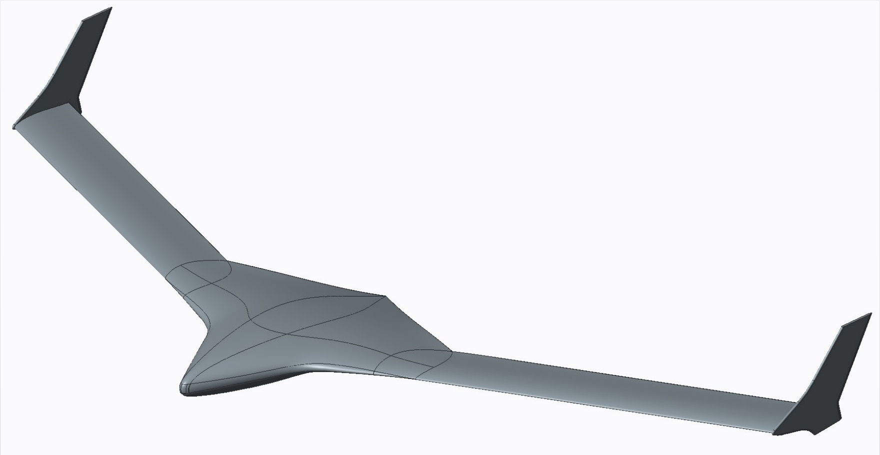
Alexander Chin

Outline

- Introduction
  - Background
  - X-56 Body Freedom Flutter Mechanism
  - Challenges in X-56 Flutter Modeling
  - Flight Test Working Group Challenge
- Individual Presentations
  - Steve Massey
  - Jos Aalbers
  - Jared Grauer
  - Jeffrey Ouellette
- Combined Results
- Discussion

Background

- Why flight test working group?
- Why X-56A?
- Data Released
    - CAD geometry (IGES)
    - Finite element model (NASTRAN)
    - Doublet lattice model (NASTRAN)
    - Cross sections
    - Frequency and damping from flight

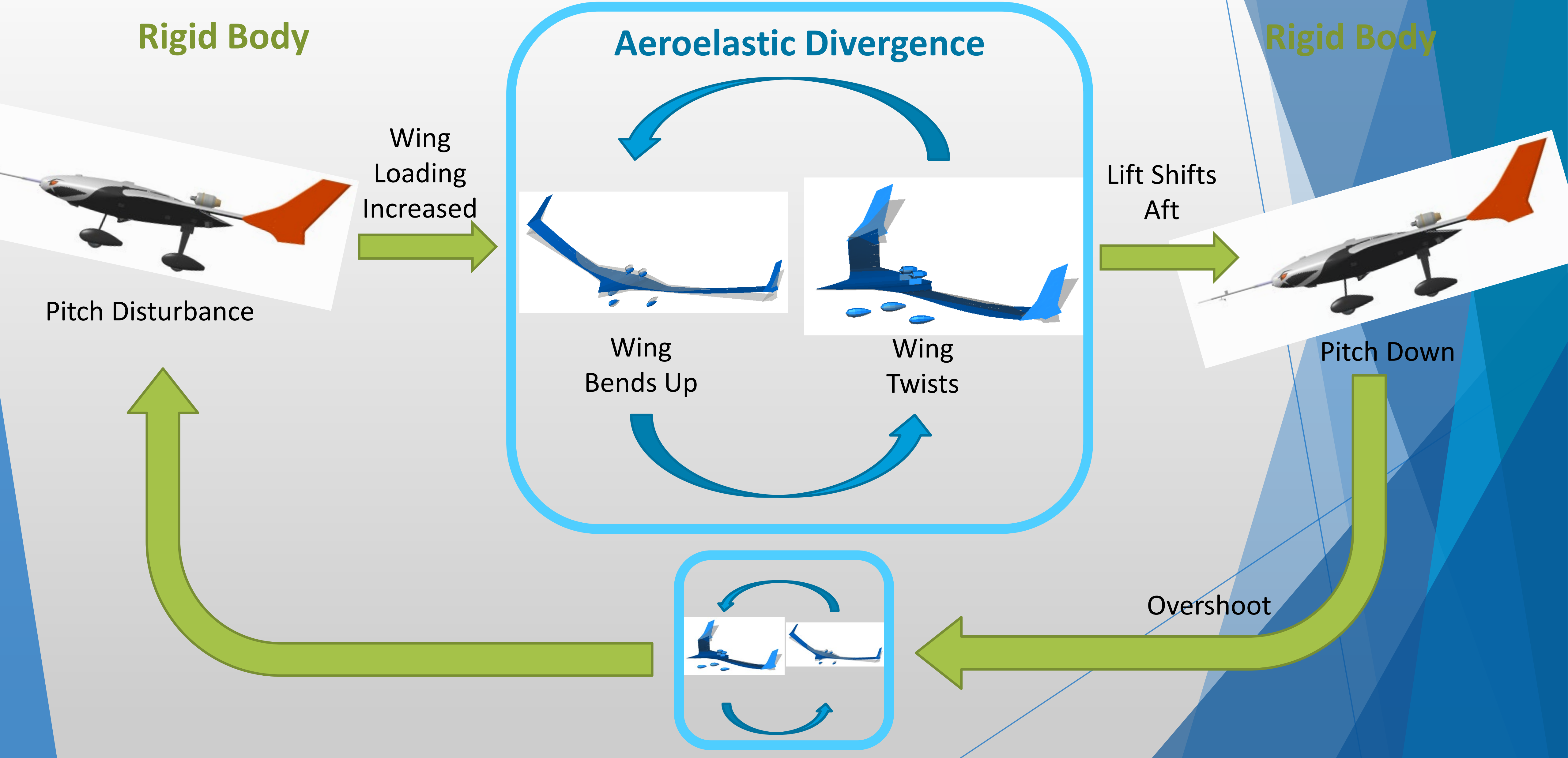


Aeroelastic Prediction Workshop, Flight Test Working Group

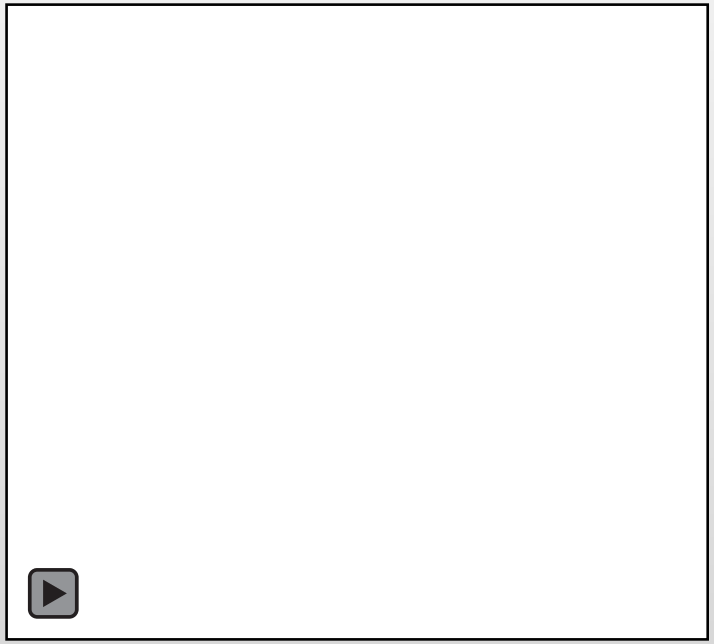
- Predict blind flutter speed with flutter mode trends
  - 0 to 200 KEAS
    - Although we only have flight data to verify first flutter mode, BFF, we can still examine secondary flutter modes at higher speeds for comparison
  - Based on mass condition (fuel) dependency
  - Aero model formulation
  - Vg and Vf trend plots
  - Leverage flight data as truth model for comparison studies (measured damping and frequency)

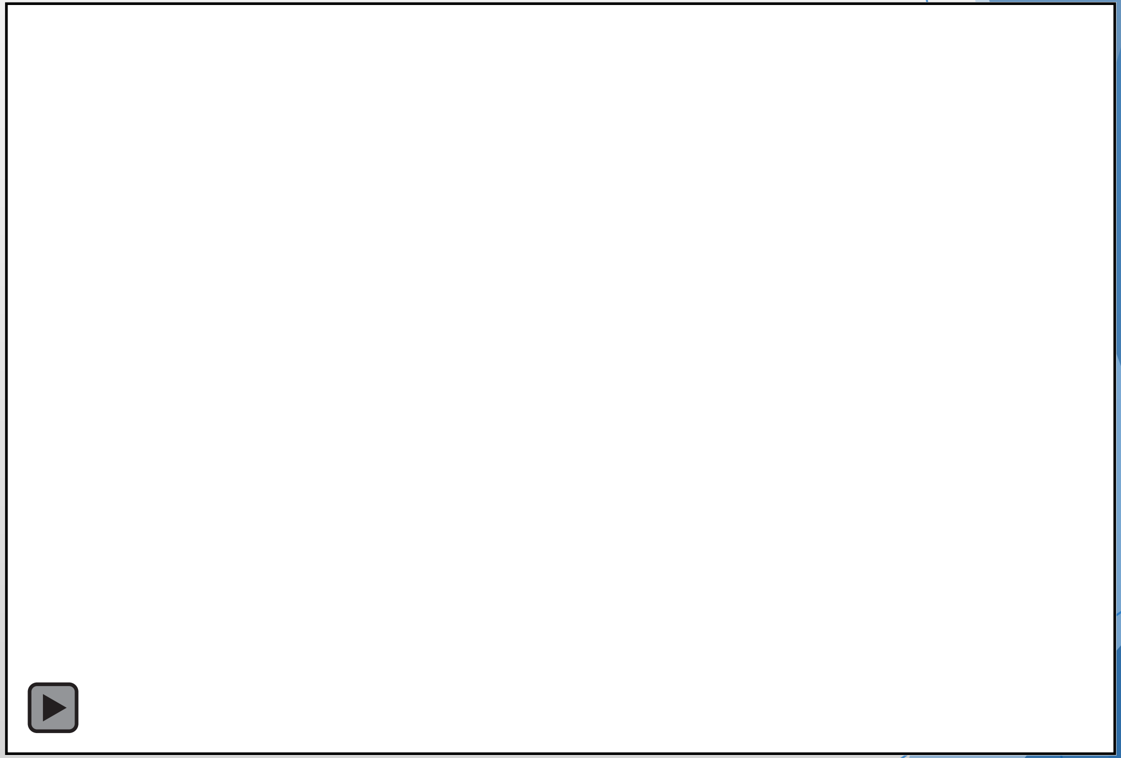
Document and present modeling approaches and assumptions

X-56 Body Freedom Flutter Mechanism



Body freedom flutter mode shape

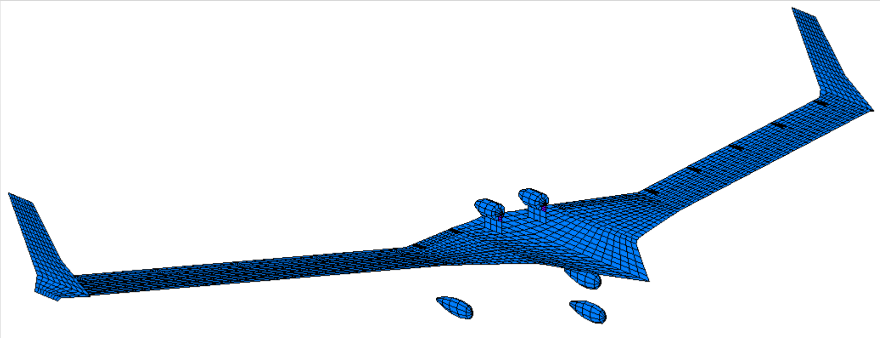




Challenges in X-56 Flutter Modeling

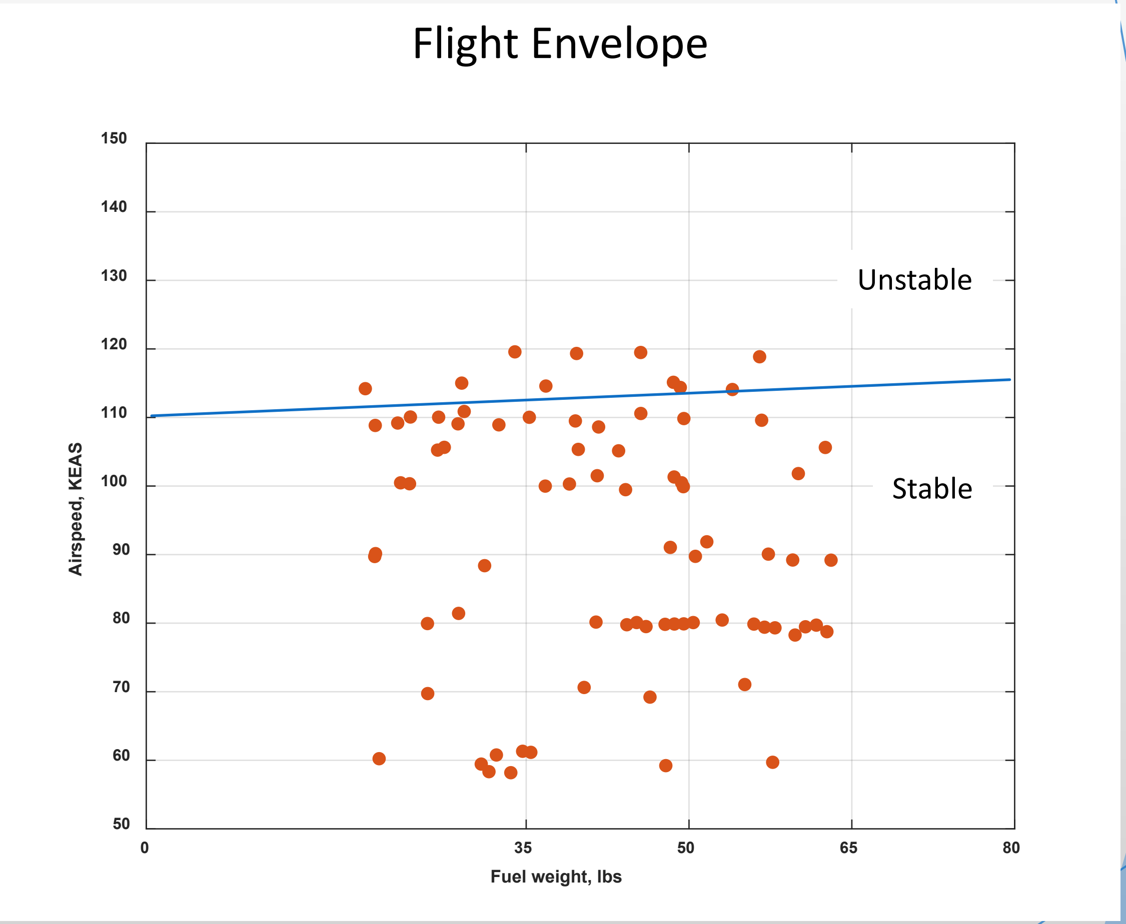
- Rigid body modes
- Winglet/wing interaction
- Thick lifting center body
- Engine/airframe interaction

Credit: NASA/Lauren Hughes



Flight Testing

- Flight Envelope
  - Fuel Weight
  - Airspeed



Individual Presentations

Steve Massey

Jos Aalbers

Jared Grauer

Jeffrey Ouellette

Modeling and Flight Test Results

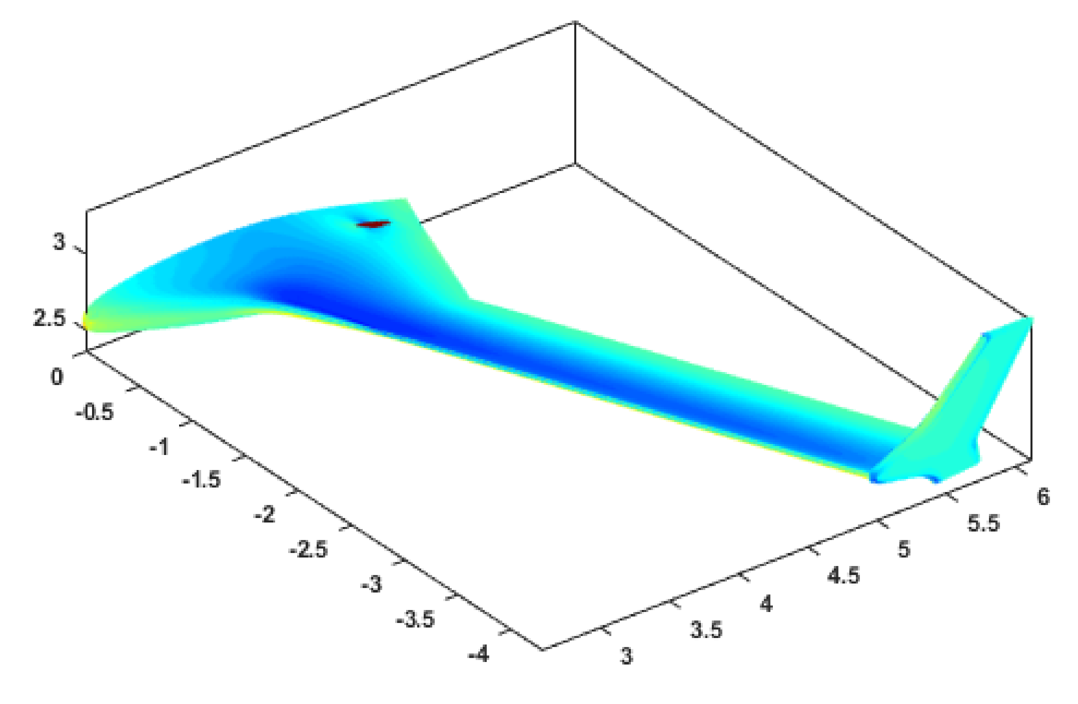
Jeffrey Ouellette, Felipe Valdez, Chris Miller, Matthew Boucher

Modeling Results

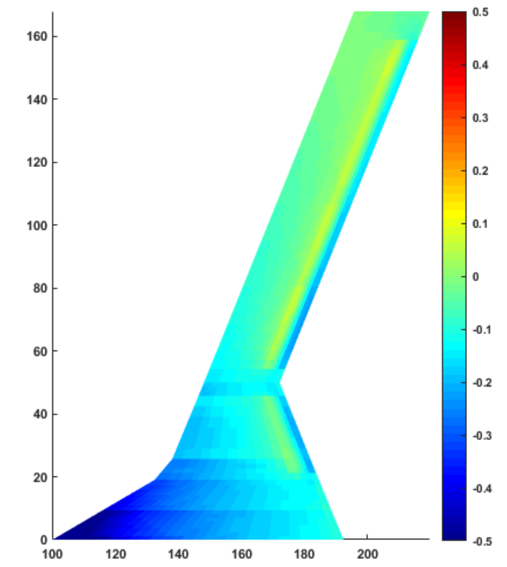
- Jeffrey A. Ouellette and Felipe D. Valdez. "**Generation and Calibration of Linear Models of Aircraft with Highly Coupled Aeroelastic and Flight Dynamics**," AIAA 2020-1016. *AIAA SciTech 2020 Forum*. January 2020.
- Corrected doublet lattice
  - Downwash correction
  - Correction of mean shape
- Augmented doublet lattice
  - Gravity
  - Trim forces
  - Drag

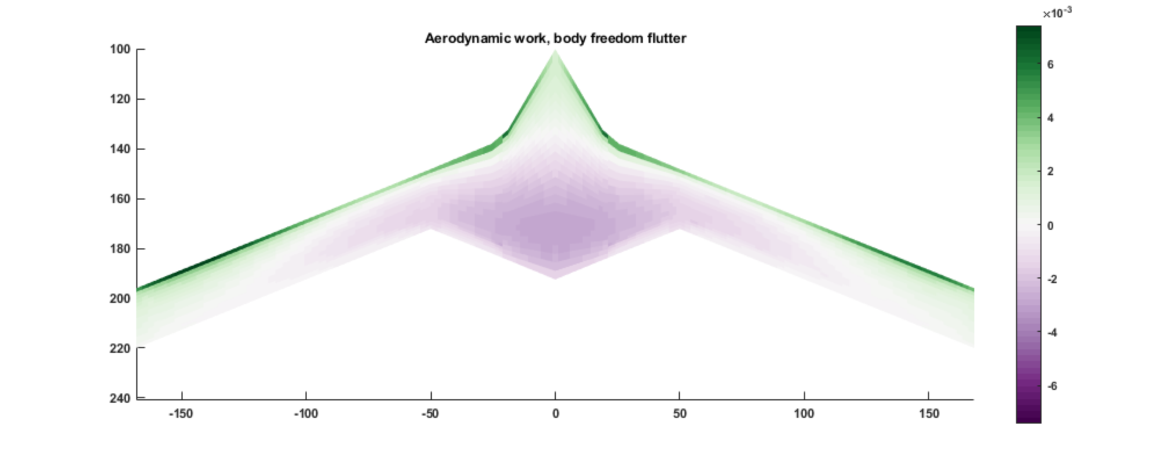
Steady CFD (STAR-CCM+)

- Steady RANS
- Geometry was different from workshop
  - Engines (flow through)
  - Landing gear
  - Half-span
- Two angles of attack
- Data splined to doublet lattice grid



Aerodynamic correction factors





Flight Test Results

- Jeffrey A. Ouellette, Chris J. Miller, and Matthew J. Boucher. "**Frequency Domain Quasi Maximum Likelihood Identification of Low Order Aeroservoelastic Models from Flight-Test Data,**" *AIAA Scitech 2023 Forum*. January 2023.
  - Monday 14:40, Baltimore 5
- Transfer function fit to multisine maneuvers

$$\boldsymbol{H} = \frac{\boldsymbol{N}_6 s^6 + \cdots + \boldsymbol{N}_1 s + \boldsymbol{N}_0}{\prod_{j=1}^{3}\left(s^2 + 2\zeta_j \omega_{n_j} s + \omega_{n_j}^2\right)}$$

  - Three modes (pitch, bending, torsion)

Combined Results

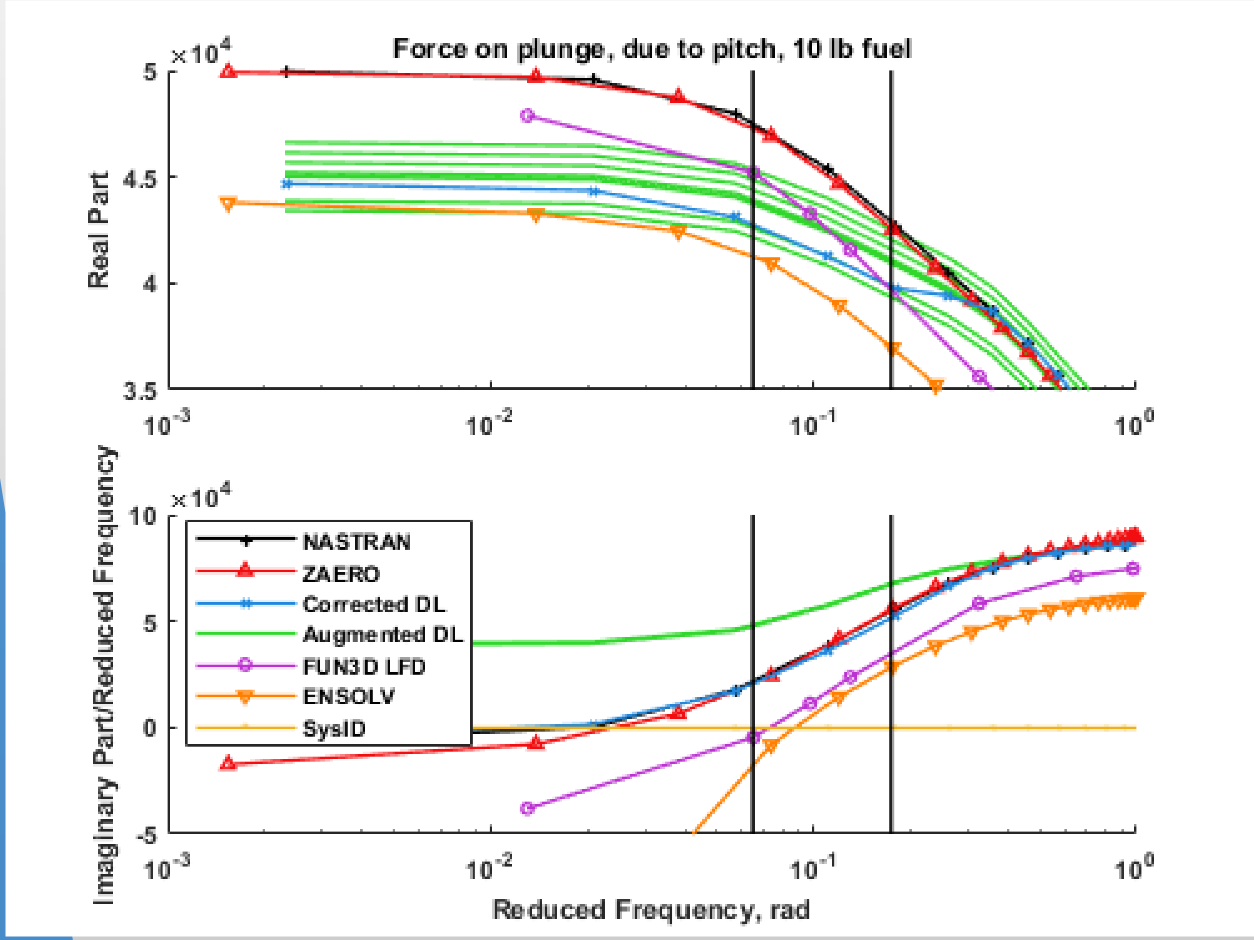
Combined Results

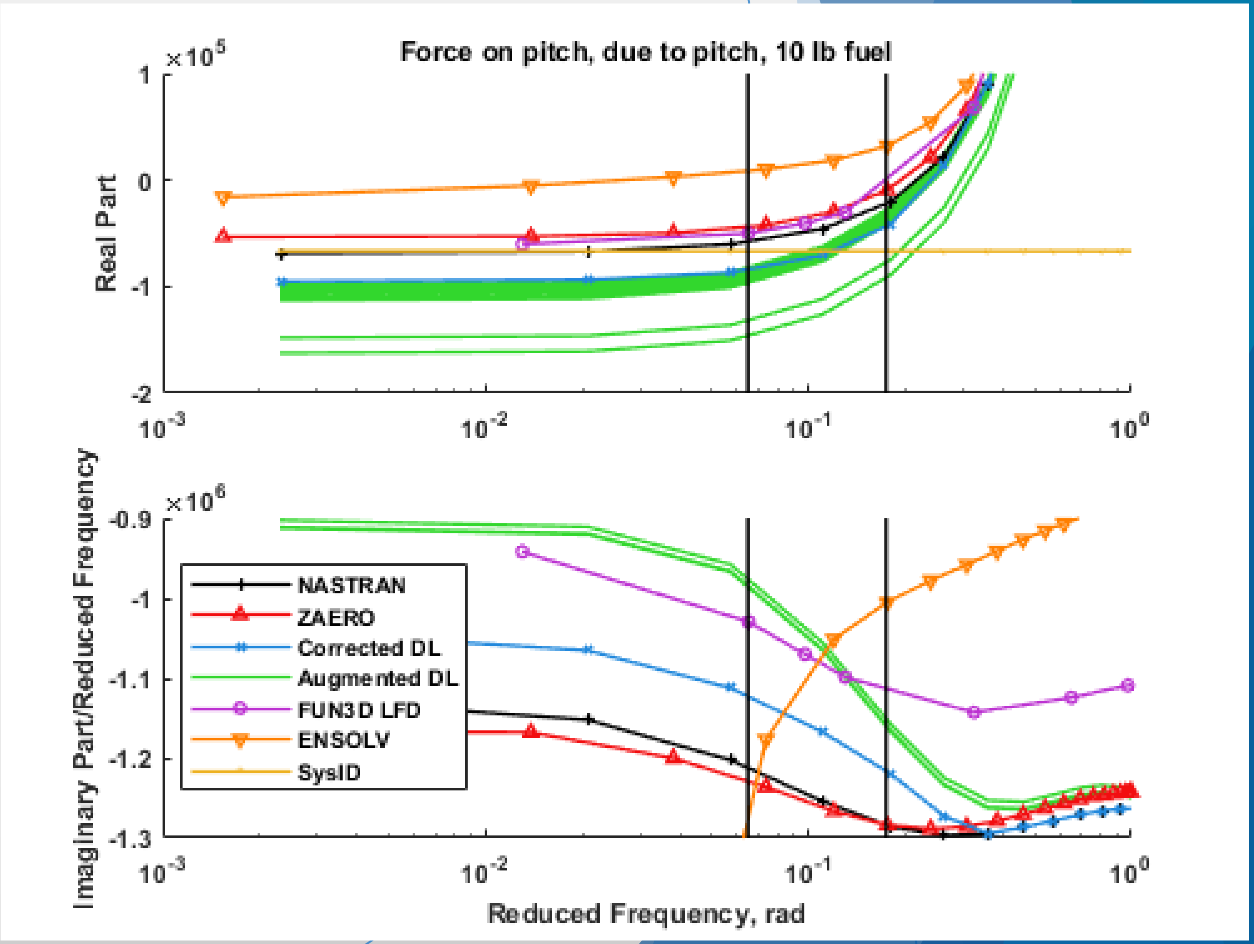
Code	Methods	Analysis Team
FUN3D LFD	RANS	Steve Massey, Bret Stanford, Kevin Jacobson
ZAERO	Linearized Potential Flow	Jos Aalbers, Huub Timmermans, Iren Mkhoyan and Peter Blom
ENSOLV	RANS	
SysID	Flight Data	Jared Grauer
NASTRAN	Linearized Potential Flow	Jeffrey Ouellette, Felipe Valdez, Chris Miller, Matthew Boucher
Corrected DL	Hybrid lifting surface	
Augmented DL	Hybrid lifting surface	
LOES	Flight Data	

Generalized Aerodynamic Forces

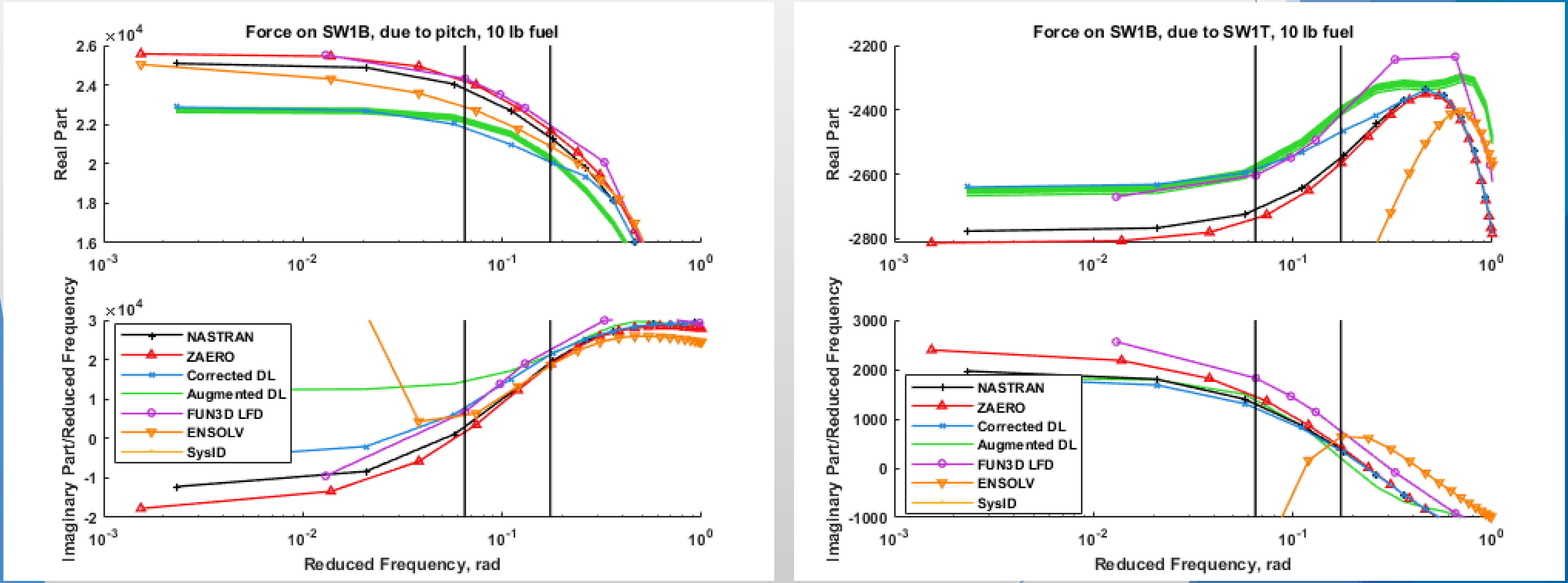
- Modes
  - Pitch
  - Plunge
  - Symmetric Bending
  - Symmetric Torsion
- 10 lb of fuel only
- Real Part
  - Forces in phase with deflections
  - Stiffness
- Imaginary Part/Reduced frequency
  - Forces in phase with rate
  - Damping

Lift and pitch moment due to pitch





Bending moment due to pitch and twist



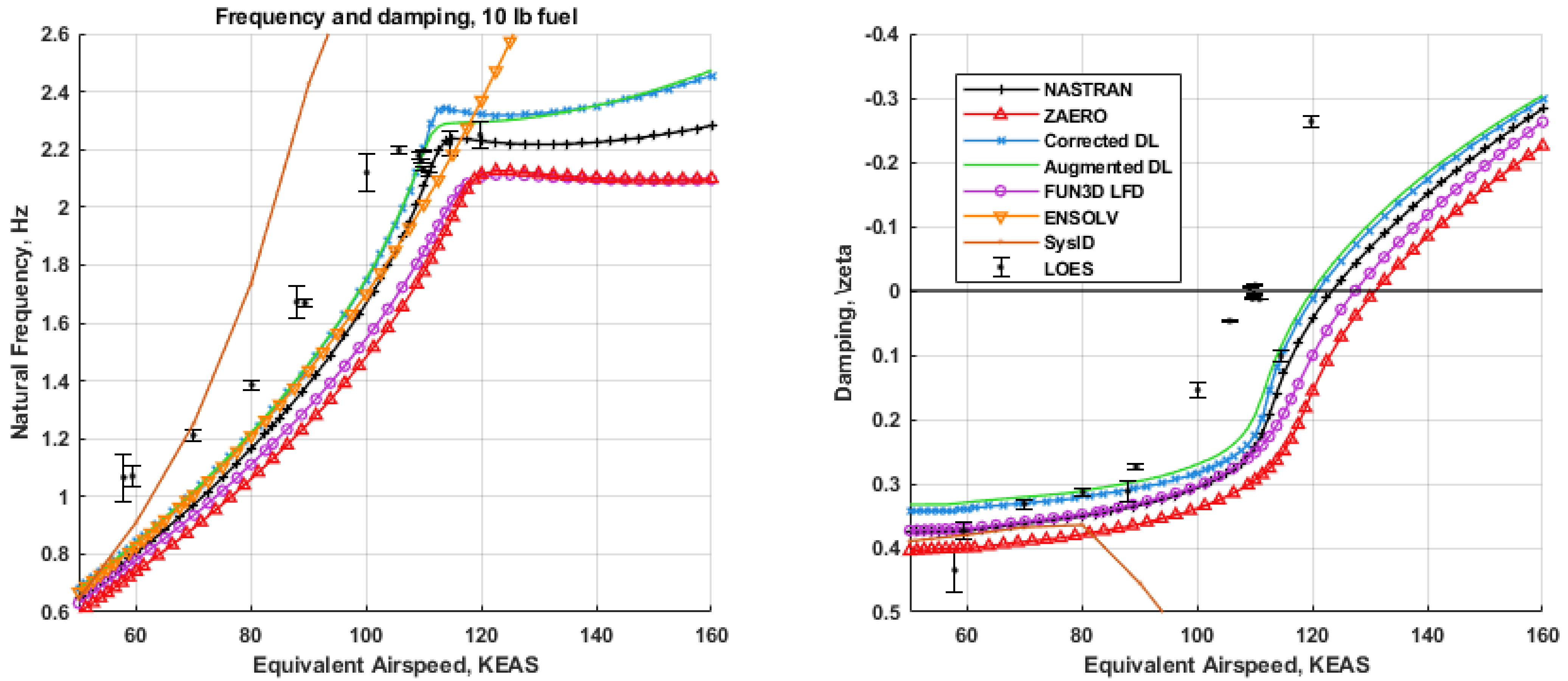
Frequency and Damping

- Poles are

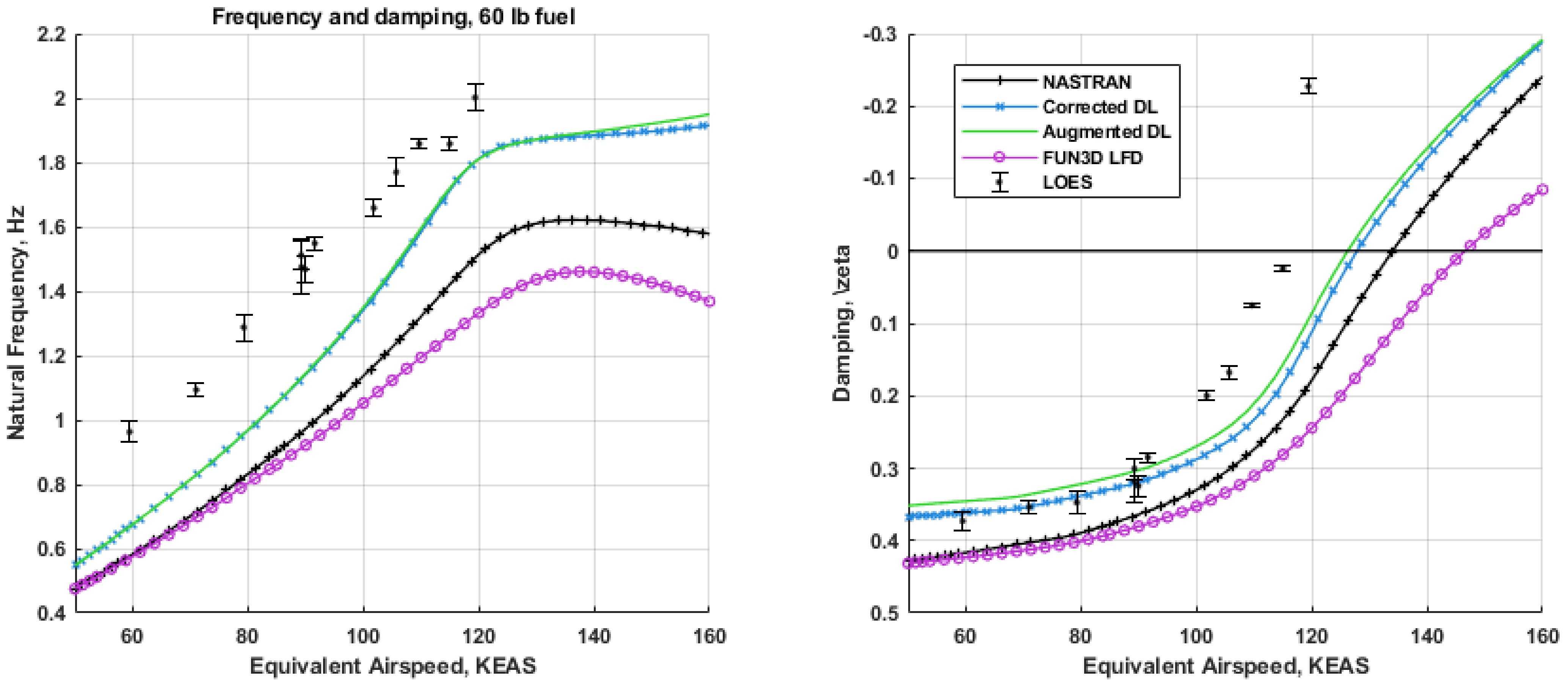
$$P = \left(-\zeta \pm i\sqrt{1-\zeta^2}\right)\omega_n$$

  - ω_n, natural frequency
  - $\zeta = 1$, critically damped
- Airspeed in knots equivalent airspeed

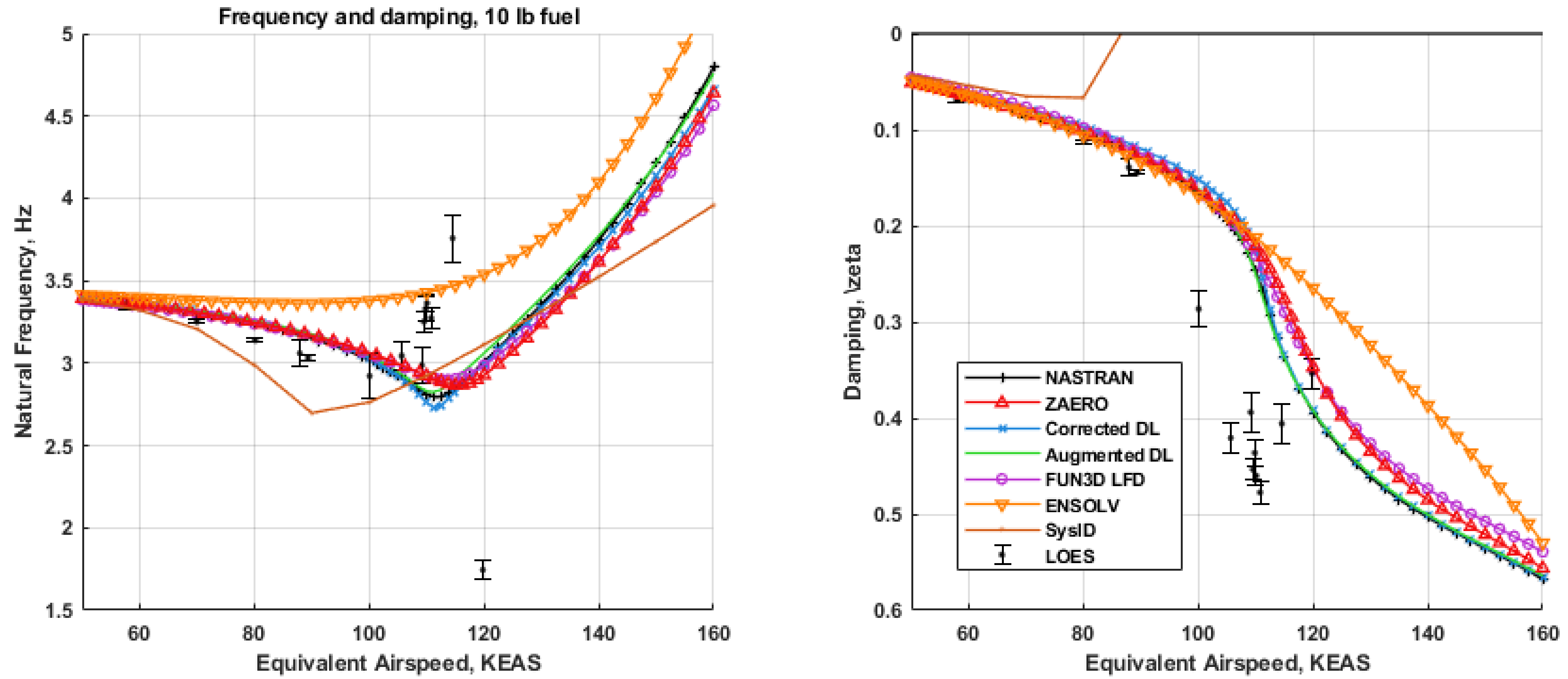
Frequency and damping
Body freedom flutter, low fuel



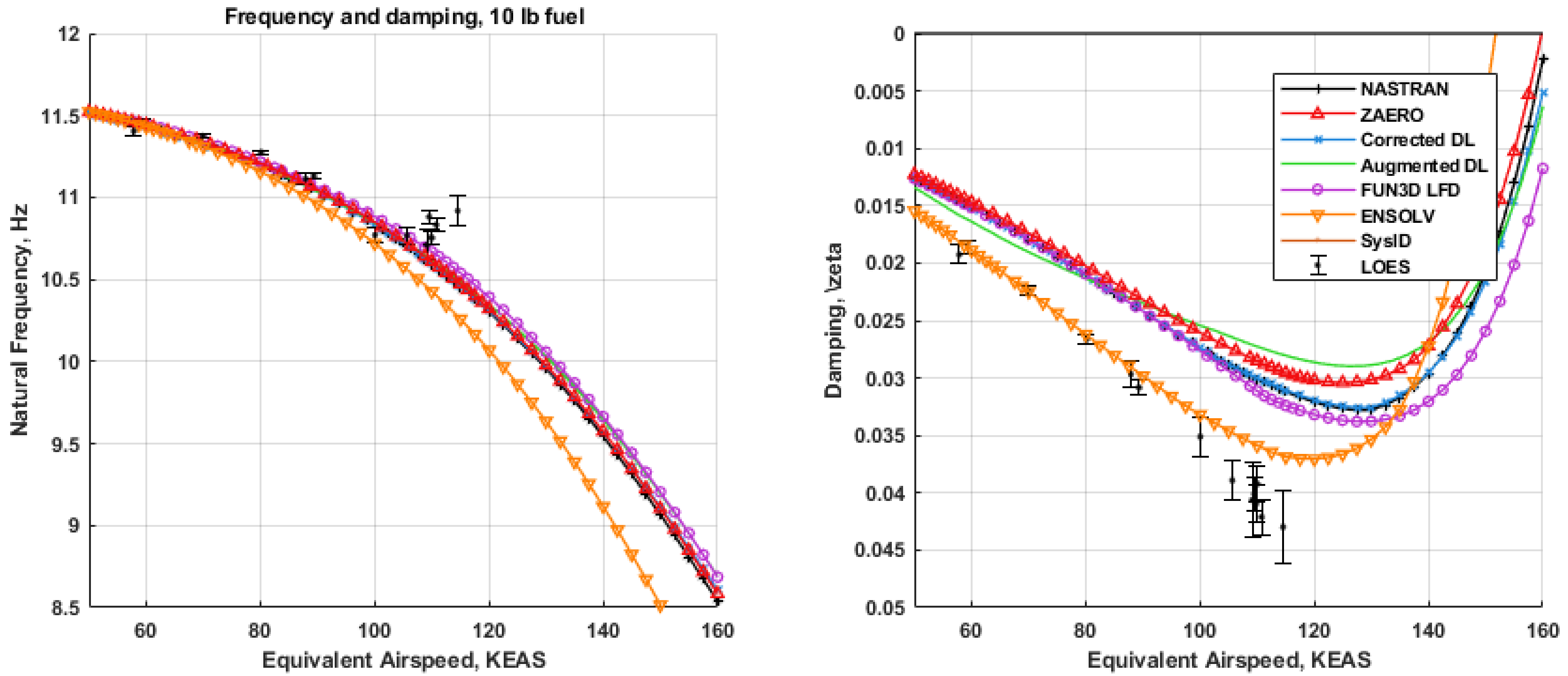
Frequency and damping
Body freedom flutter, heavy fuel



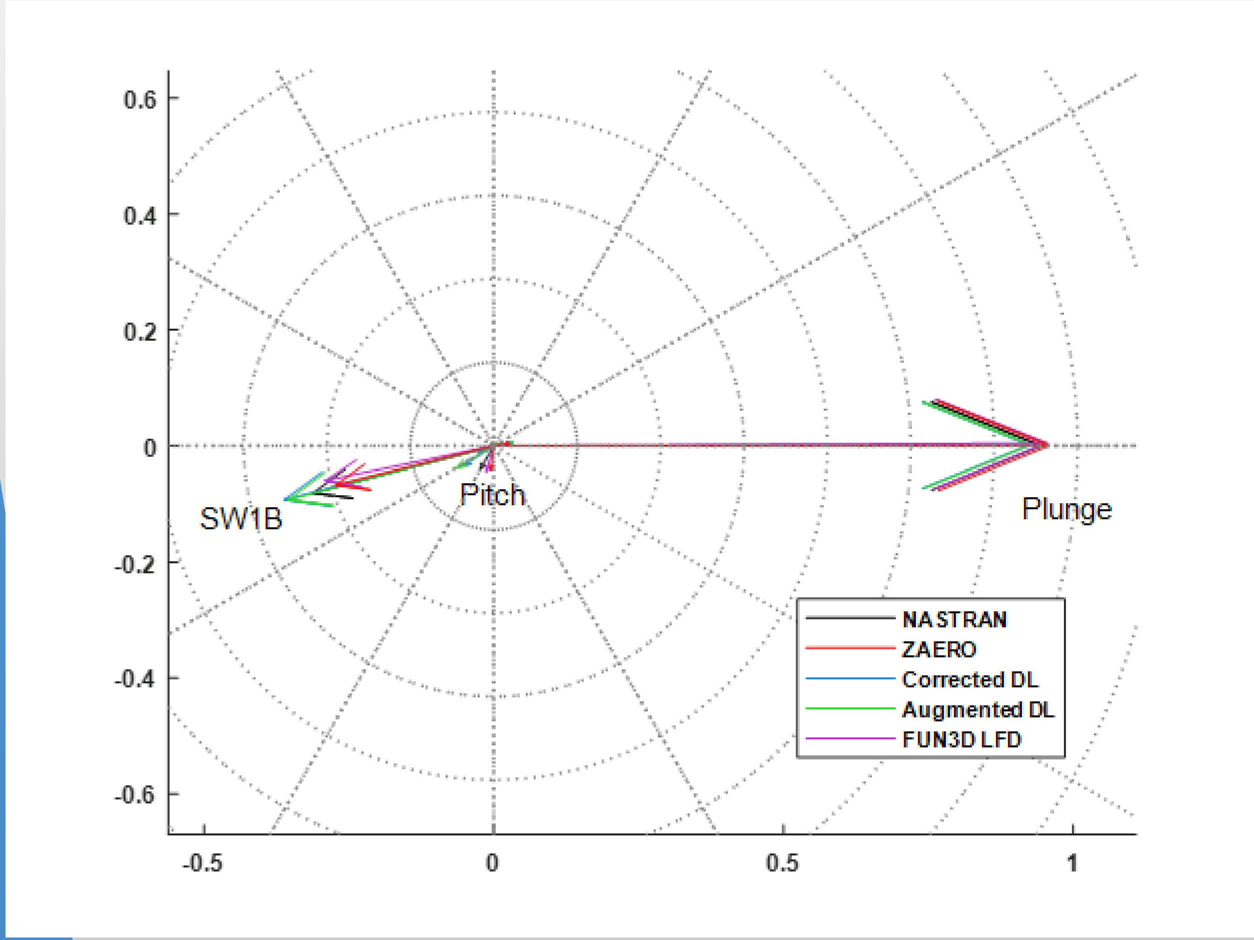
Frequency and damping
Wing bending, low fuel

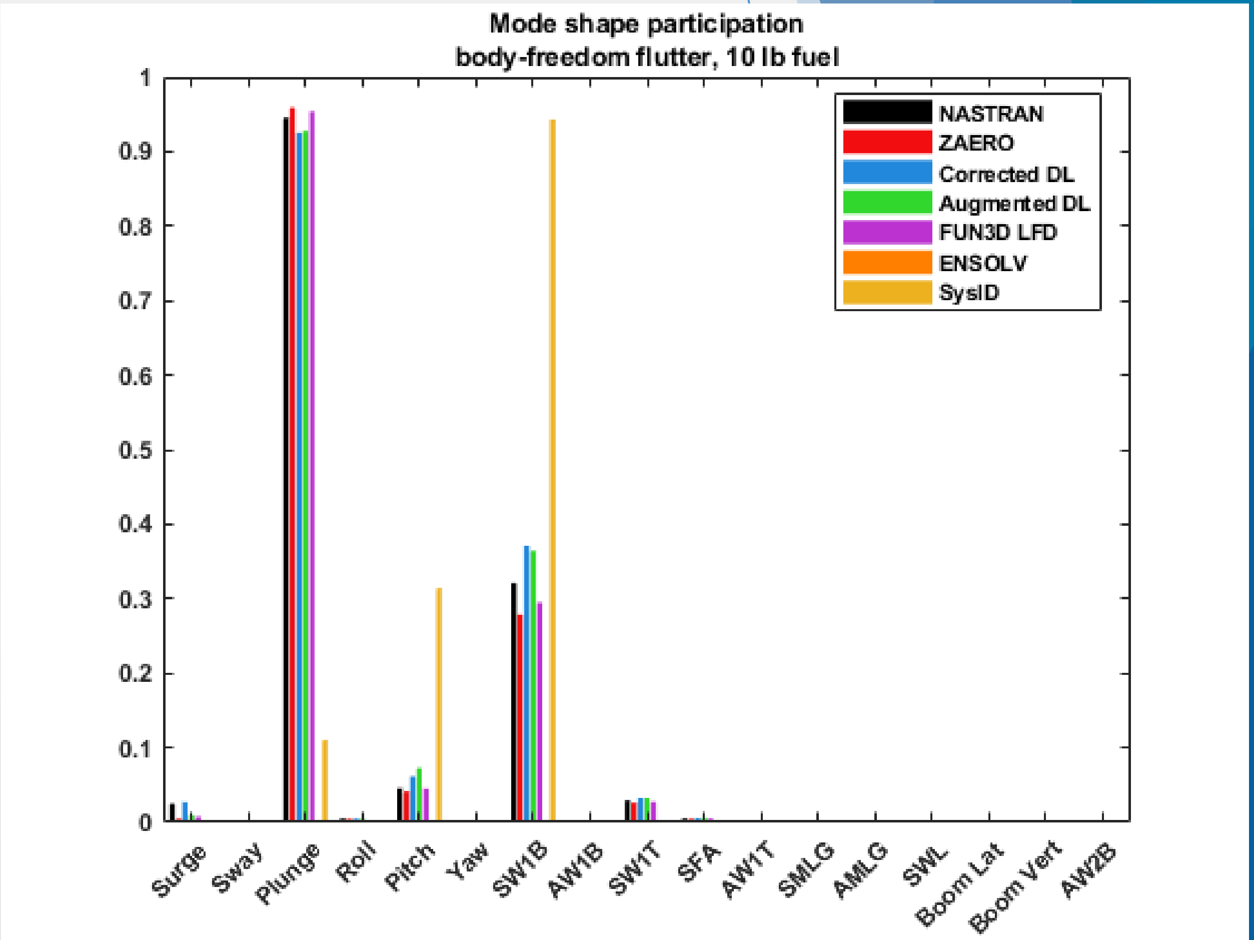


Frequency and damping
Wing bending/torsion flutter, low fuel



Body freedom flutter mode shape





Aerodynamic Energy

- Aerodynamic energy

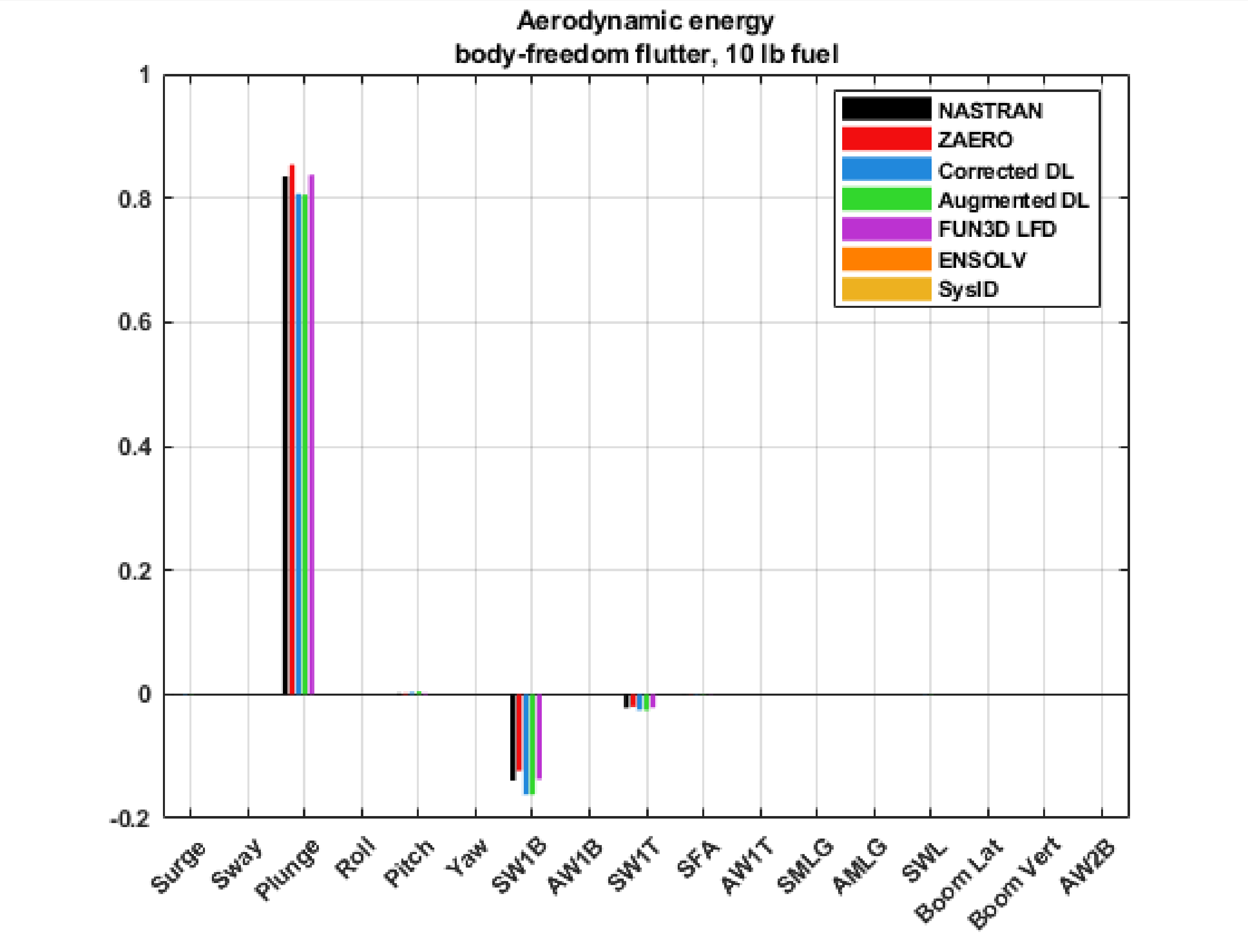
  $real(conj(\boldsymbol{f}) \circ \boldsymbol{u})$

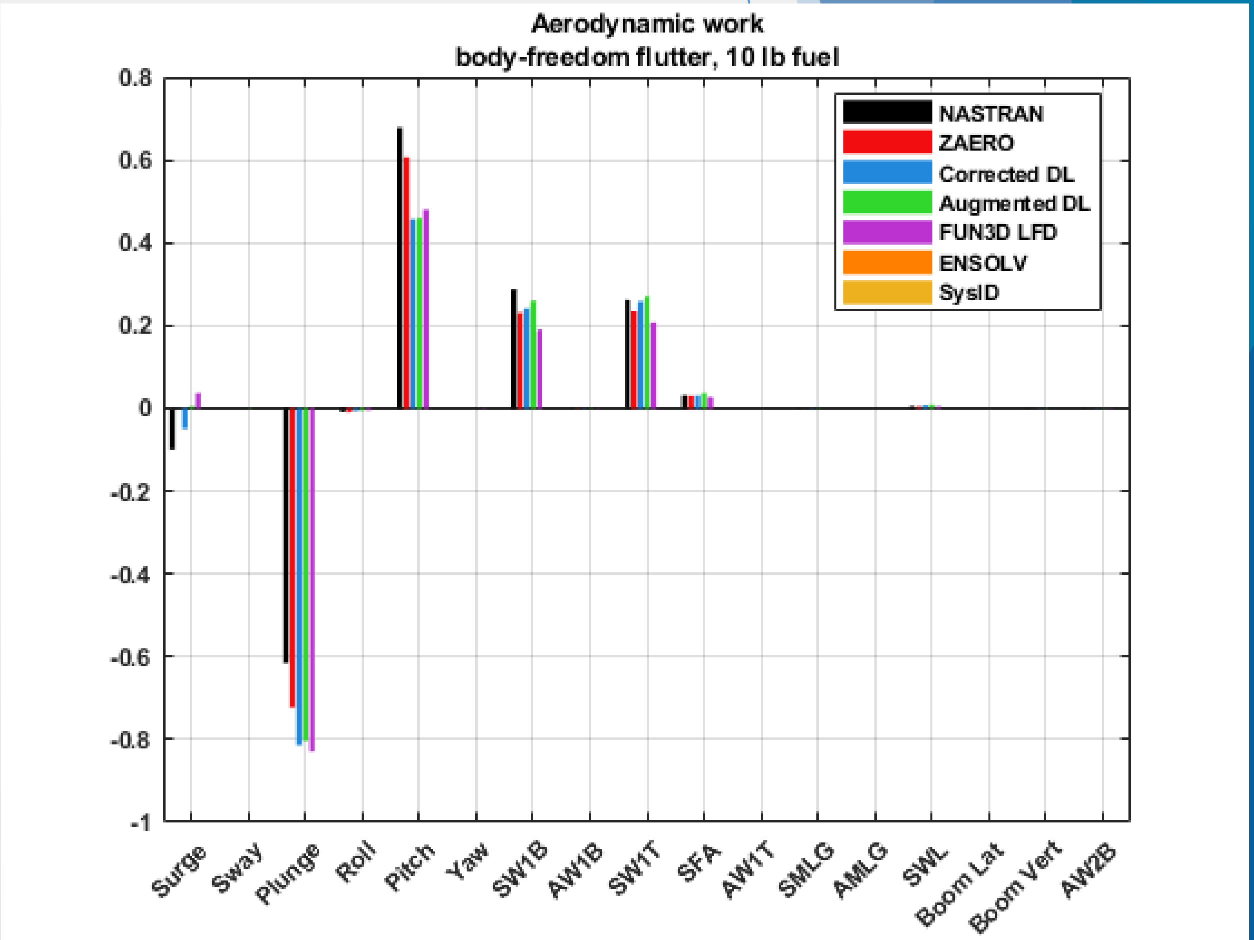
  - Conservative work due to flow field
  - Balanced with kinetic and strain energy
- Aerodynamic work

  $imag(conj(\boldsymbol{f}) \circ \boldsymbol{u})$

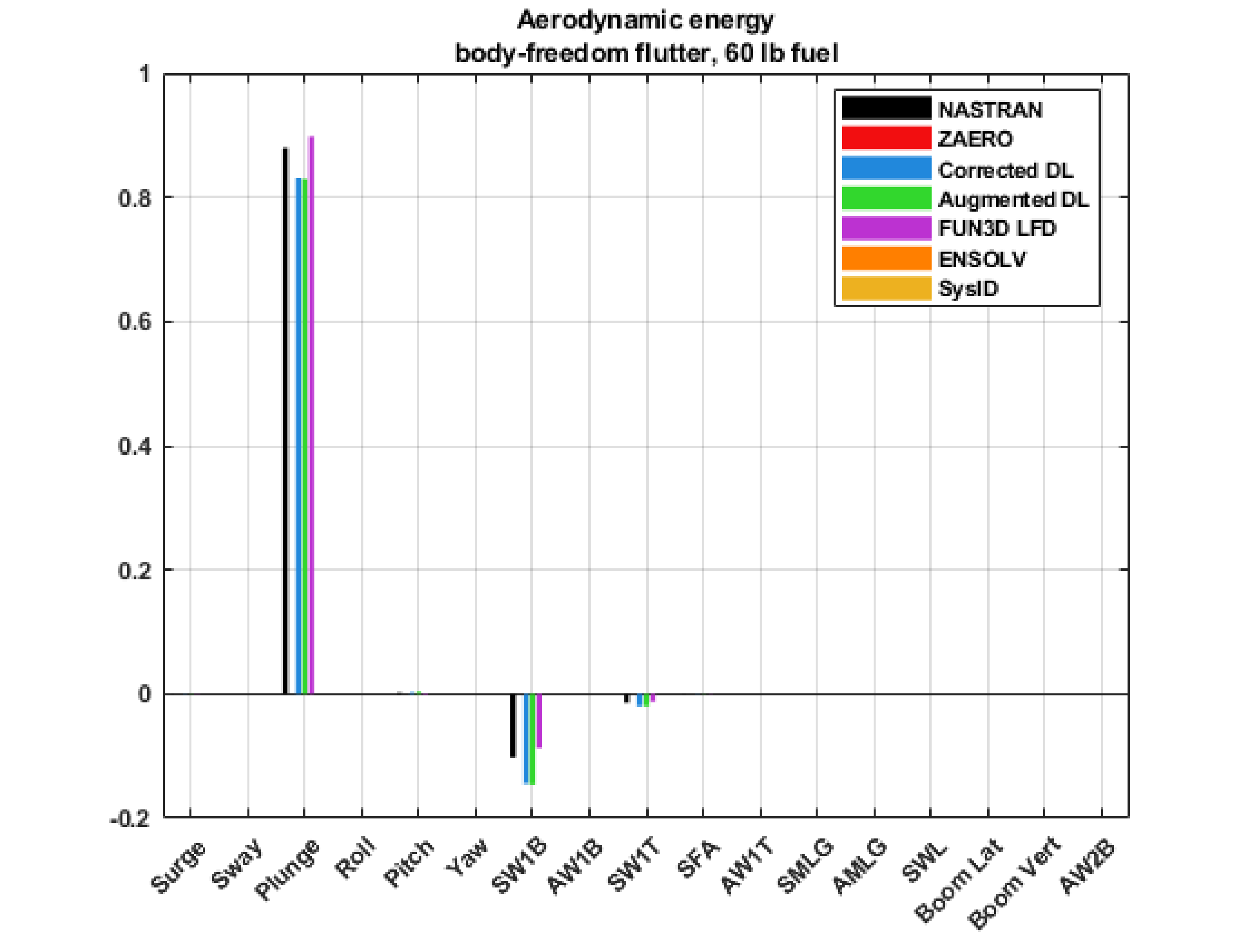
  - Nonconservative work over the cycle
  - Balanced by structural damping
  - Which modes are destabilizing
- Normalized to correct for dynamic pressure

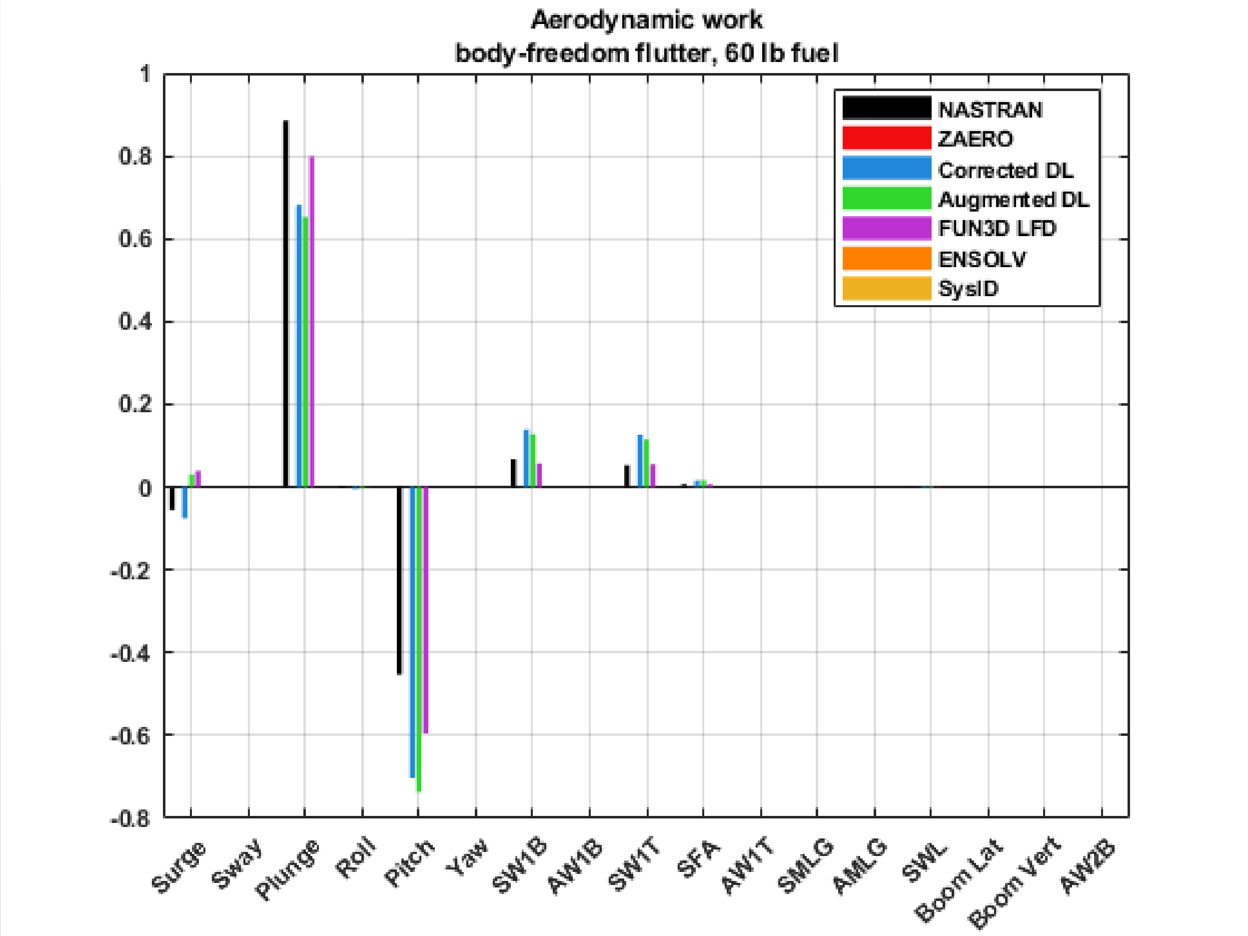
Aerodynamic energy and work
Low fuel



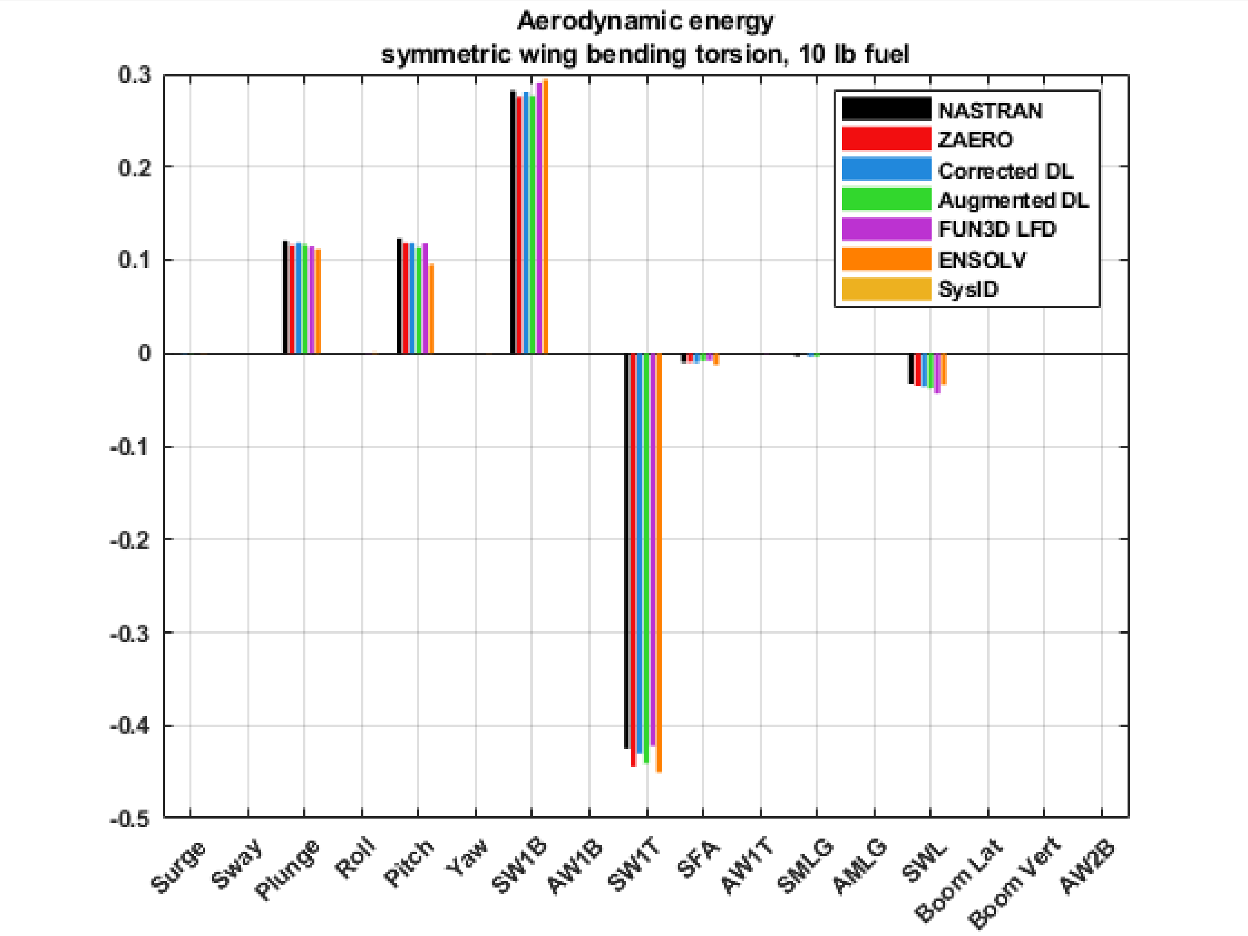


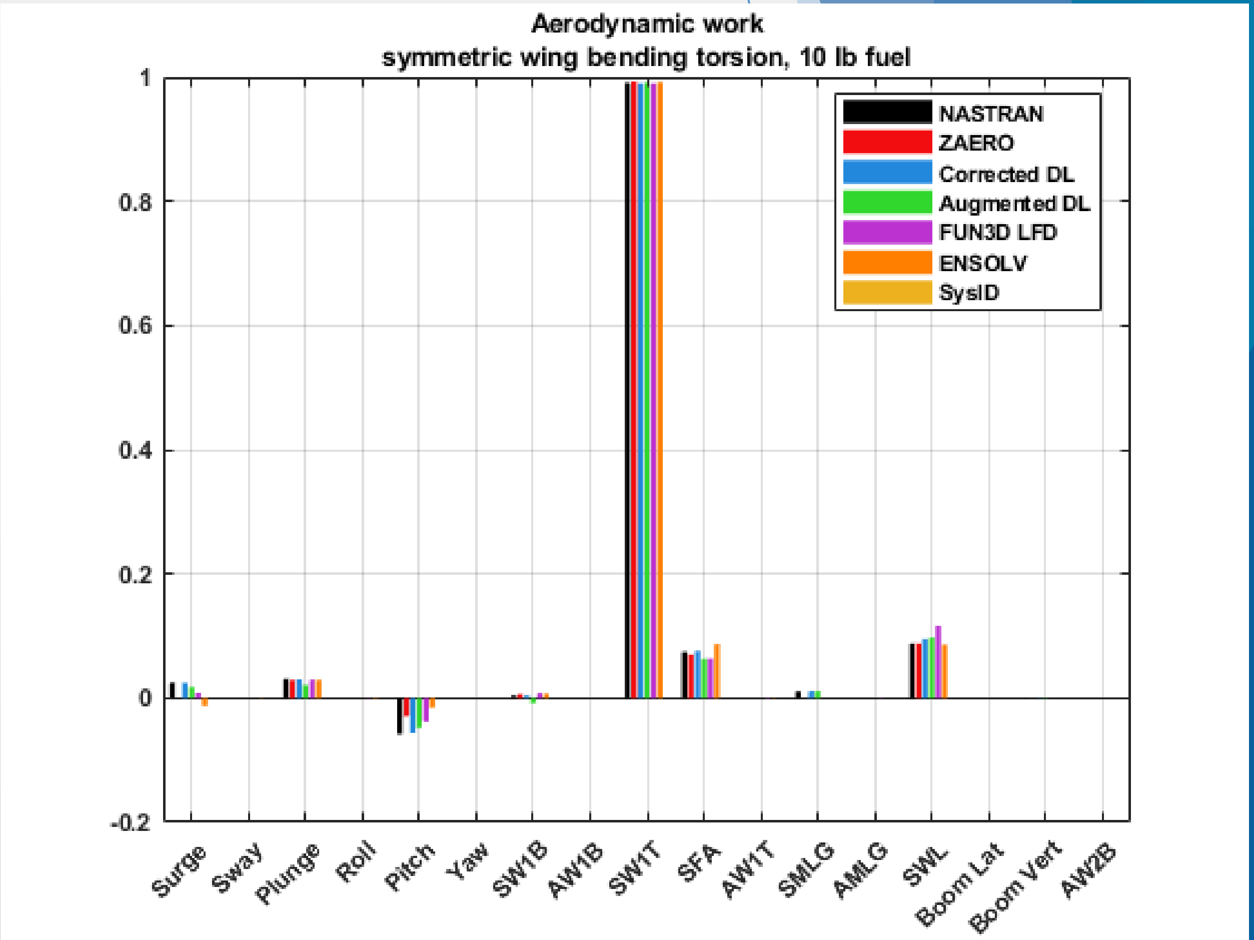
Aerodynamic energy and work
Heavy fuel





Aerodynamic work
Classical symmetric bending/torsion flutter





Next Steps

- Is there interest in continuing with X-56 analysis?
  - Engine/Airframe interaction?
- New configuration?
  - Body-freedom flutter
  - Aeroservoelasticity